The I-MECH project aims to create a state of the art and enabling technologies of motion control systems for smart mechatronics and robotics devices. To do so, the project identifies the gaps between the state-of-the-art in motion control in industry, the state-of-the-art of motion control in research, the needs of the 'smart and resilient' manufacturing industry in Europe and connects to specific project pilots, use cases and demonstrators. The objectives are: (a) to develop techniques for employment of advanced model-based methods for the design, real-time control and self-diagnosis of
cyber-physical systems, (b) to develop a smart Instrumentation Layer gathering visual and/or sensor information from supplementary instrumentation installed on the moving parts of the controlled system to enhance the achievable performance of the system, (c) to develop modular unified, Hardware and Software motion control building blocks implementing a service-oriented architecture paradigm, i.e. smart Control Layer, and to prepare interfaces to a state of the art predictive maintenance platform and develop specific condition monitoring building block providing relevant data for system behaviour layer.

Furthermore, I-MECH aims to integrate the developed building blocks into a conceptual open platform for intelligent control of industrial mechatronic systems and deploy the platform on commercial HW and commercial industrial robots.

The importance to society lies on the developed technologies in industrial printing, semiconductor production, high-speed packaging, smart machining tools, and high precision CNC milling machines, and healthcare robotics. The consortium started to establish the I-MECH Center which ensures sustainable cooperation between consortium partners after the project termination in terms of ECS products and services. It will be open also for new interested parties (SME, LE, RTD, UNI) outside the I-MECH consortium. Also, it is believed that, through such a center, I-MECH will become a European solution desk for advanced motion control in cyber-physical systems. The project helps to understand future development of complex machine digital twins and role of AI in industrial control systems, fulfilling the directions of ECSEL Industry4.E Lighthouse.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

The project created the I-MECH architecture with three layers: Instrumentation layer, control layer, system behaviour layer. Additionally, the subsystem-level (called Building Blocks) requirements have been identified for the total of 11 building blocks.

The I-MECH platform directly contributes to one of the ECSEL main objectives to move towards more digitized and highly automated production. The shortcomings of the current motion control ecosystem have been identified and a plan for progress beyond the state of the art has been established as part of the I-MECH platform building blocks:

- Employment of advanced model-based design techniques for the development of smart robust control strategies both for decentralized single-loop problems and centralized solution for complex multivariable systems (BB6, BB8)
- Development of automatic procedures for the acquisition of plant dynamics models and the consequent choice of a proper control structure for tuning of the controller parameters (BB6, BB7, BB8, BB9)
- Development of high-fidelity models of mechanical systems (beyond the traditional simplifying assumptions of rigid-body mechanics) enabling a significant performance enhancement for systems with flexible dynamical behavior e.g. dynamic stiffness control (BB7, BB8). Such model will become a core of future reliable digital twins.
- Integration of the additional sensory information about load-side motion to the advanced control schemes (BB1, BB4) using flexible and scalable SoC+FPGA HW architecture
- Development of robust protocols for wired and wireless data transmission suitable for high-speed real-time operation of motion control elements focusing on energy efficiency, security and reliability
Development of advanced cost-efficient solutions for monitoring, diagnostics and predictive maintenance of the electromechanical components of motion control systems allowing safe, robust, accurate and reliable operation (BB3)

Development of open architecture HW platforms capable of execution of the co-developed software modules allowing easy scalability and reconfigurability according to specific user requirements (BB5, BB10, BB11)

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

With regards to the I-MECH System Behaviour Layer, the system behavior in terms of the desired motion trajectory is explored as it addresses the fundamental demands which originate from the management layers of production systems. Functionality such as user interaction, sequence and/or exception management are also part of the exploratory work. OPC-UA and EtherCAT are considered as enabling protocols.

I-MECH Control Layer: implemented and tested BBs on pilots, use-cases and demonstrators:
BB7 Vibration control module
BB8 Robust multivariable control modules
BB9 Iterative and repetitive control module
BB11 RTOS for Multi many Core Control

For BB7, the project partners have defined new concepts for set-point adaptation strategies, input shaping, MPC, I/O inversion and acceleration feedback to damp vibrations at the POI.
For BB8, the focus was on improving performance of high-precision applications by incorporating MIMO controllers to take interaction into account and robustness for higher reliability.
For BB9, the research has been focused on two main approaches: Iterative Learning Control to improve setpoint tracking in repetitive movements and Repetitive Control to improve setpoint tracking facing repetitive disturbances. Performance improvements are already visible on pilots.
For BB11, the work had followed the direction to develop a framework for PIL and HIL configurations (BB11) for controllers considering CPU (COTS) and FPGA platforms (BB10).

I-MECH Instrumentation Layer: implemented and tested BBs on pilots, use-cases and demonstrators:
BB1 Platform for Smart Sensors with Advanced Data Processing
BB2 Real-time wireless sensors providing complementary feedback information
BB4 High speed vision
BB5 High Performance Current amplifier
BB10 Control specific multi-many core HW
BB11 RTOS for Multi many Core Control

Main hardware component developed was the main backbone communication interface - EtherCAT. The requirements and specifications for the project Use-cases, Pilots and Demonstrators were
updated accordingly. That work led to more detailed functional, operational and design requirements and specifications.
For BB1, high-level concepts for SoC+FPGA architecture were defined by considering also the modularity and interfaces for BB2 and BB4. In addition, synergy possibilities with BB10 were explored.
For BB2, development and testing of first five real-time wireless sensors were performed, leading to improvement options for the next prototypes. BB2 successfully can now create control structures with BB1
For BB4, the development of the high-end high-speed vision able to be used in fast feedback control loop continued according to pilot requirements.
For BB5, the work on high performance current amplifier motion stage (PCB) resulted into prototypes which were tested on pilots and use-cases.
For BB11, the partners developed a multi-many core control board to provide a versatile and cost-effective motion control solution for complex mechatronic systems.

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